Combination of the IGS repro2 terrestrial frames

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Introduction A

Eight IGS Analysis Centers (ACs) have completed a second reanalysis campaign (repro2) of the GNSS data collected by the IGS global tracking network back to 1994, using the latest available models and methodology (http://acc.igs.org/reprocess2.html). The AC repro2 contributions comprise in particular daily terrestrial frame solutions (SINEX files) including station coordinates and Earth orientation parameters. The AC daily terrestrial frame solutions have been combined by the IGS Reference Frame Working Group. The obtained daily combined solutions form the IGS contribution to the next release of the International Terrestrial Reference Frame (ITRF2014).

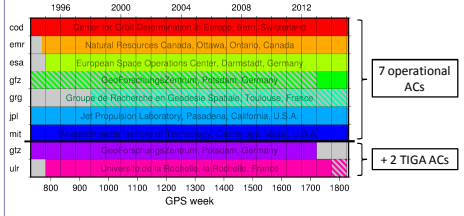

Figure 1: AC contributions to the repro2 campaign

- *Plain color: AC contribution included with weight in the combination*
- *Hatched color: AC contribution included for comparison only*
- *Grey: Unavailable contribution*

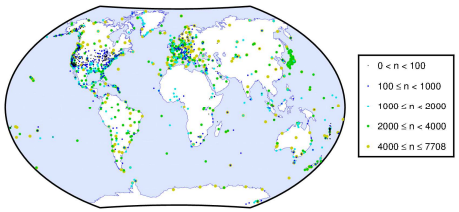

Figure 2: Stations included in the daily repro2 combined solutions. The size and color of each dot is function of the number of days n each station is present.

Station position residuals B

With a few exceptions, the daily station position estimates provided by the different ACs are of homogeneous quality: the inter-AC agreement is at the level of ≈1.5 mm in horizontal and ≈4 mm in vertical after 2004 (Figure 4). The exceptions include:

- **COD:** higher noise level before ≈1999, especially in East (Figures 3, 4) – ambiguity resolution?
- **EMR:** higher WRMS in North, likely due to small, unexplained station-specific biases (Figures 3, 4) – TBC
- **GRG:** substantially higher WRMS in Up (≥ 6 mm; not shown) – under investigation
- **ULR:** higher level of high-frequency white noise, especially in horizontal (Figures 3, 4, 5)

A spectral analysis of the AC station position residual time series (Figure 5) reveals distinct spectral peaks on top of a background white+flicker noise:

- **All ACs:** GPS draconitic harmonics at least up to the 15th
- **All ACs:** direct and aliased tide periods at 14.8, 14.2 and 13.6 d
- **COD & ESA:** spectral peaks at 8.2 and 7.8 d, likely related to the use of GLONASS data
- **GRG:** excessive annual power in North; unexplained spectral peak at 13.2 d in East and North; broad, unexplained spectral peaks around 3.7 and 2.2 d
- **GTZ:** unexplained spectral peaks at 16.1 d in East and 11.8 d in North
- **MIT:** spectral peak at 7 d in North, likely due to weekly-based constraints on orbit parameters

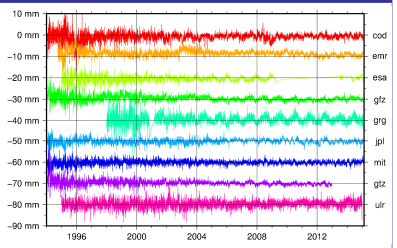

Figure 3: Example of station position residual time series Station YELL (Yellowknife, Canada) – North component

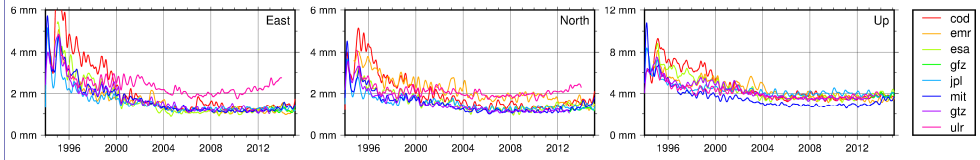

Figure 4: Smoothed, unbiased WRMS of the station position residuals from the daily combinations

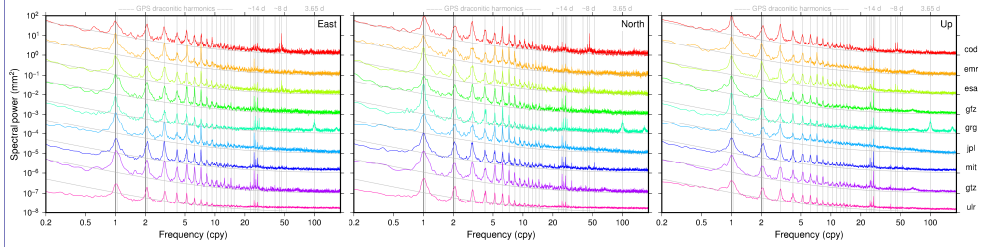

Figure 5: Stacked Lomb-Scargle normalized periodograms of the AC station position residual time series

Geocenter and terrestrial scale C

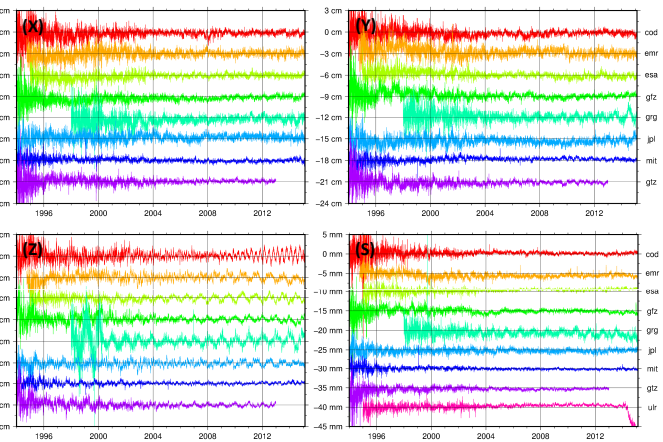

Figure 6: (X), (Y), (Z): AC geocenter residual time series.
(S): Time series of scale factors estimated between the (pre-processed) daily AC solutions and the daily combined solutions

	XGC			YGC			ZGC			scale		
	offset	rate	WRMS	offset	rate	WRMS	offset	rate	WRMS	offset	rate	WRMS
cod	-1.7	0.07	3.4	-2.2	0.10	3.5	0.9	0.18	9.5	0.2	-0.01	0.4
emr	-0.2	0.09	4.6	2.3	-0.27	5.4	1.8	-0.17	8.8	-0.5	-0.02	0.6
esa	-1.1	0.17	3.1	0.6	-0.33	3.2	-1.6	0.16	7.1	0.4	0.04	0.5
gfz	-2.4	0.22	3.8	1.6	-0.19	4.3	2.0	-0.31	8.6	-0.1	-0.02	0.5
grg	-3.9	0.29	6.0	0.8	-0.08	6.1	-0.0	0.43	12.5	-0.6	-0.05	0.8
jpl	2.0	0.04	4.4	-2.9	-0.01	4.6	-1.8	0.11	8.0	-0.2	0.00	0.5
mit	0.1	-0.14	2.2	1.7	0.04	2.2	0.2	0.05	3.6	-0.1	-0.02	0.3
gtz	0.7	0.04	2.6	-1.2	0.09	2.7	-0.0	-0.10	5.1	-0.3	0.00	0.3
ulr	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.3	0.03	0.4

Table 1: Results from linear fits to the geocenter residual time series and the scale factor time series shown in Figure 6. Offsets are given at 2005.0. Units are mm and mm/yr.

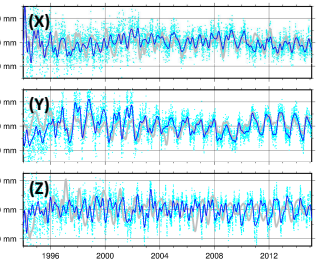

Figure 7: Comparison of the repro2 combined geocenter coordinates (wrt IGb08) with geocenter coordinates (wrt ITRF2008) derived from the SLR contribution to ITRF2014. All time series shown in the figure were detrended beforehand.
··· Daily repro2 combined geocenter coordinates
— Smoothed daily repro2 combined geocenter coordinates
— Smoothed SLR-derived geocenter coordinates

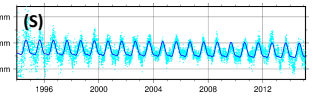

Figure 8: Scale factors estimated between the daily combined repro2 solutions and IGb08
··· Daily scale factor estimates
— Trend + annual + semi-annual fit

	XGC	YGC	ZGC	scale
offset	1.6	2.6	7.0	-1.5
rate	0.28	-0.40	-0.18	-0.03
ann amp	1.5 (2.6)	3.6 (2.8)	3.8 (5.9)	1.3
ann phase	41 (48)	310 (320)	181 (26)	247
semi-ann amp	0.9 (0.8)	0.2 (0.3)	1.3 (1.4)	0.5
semi-ann phi	271 (282)	336 (159)	223 (202)	120
WRMS	3.5 (2.9)	3.5 (2.9)	6.4 (5.2)	0.8

Table 2: Results from trend + annual + semi-annual fits to:
(a) the repro2 combined geocenter time series (wrt IGb08)
(b) geocenter time series (wrt ITRF2008) derived from the SLR contribution to ITRF2014
(c) the scale factor time series shown in Figure 8
Offsets are given at 2005.0. Units are mm, mm/yr and deg.

Summary:

- Excellent agreement between the scales of the AC solutions (< 1 mm; < 0.1 mm/yr; see Figure 6 (S), Table 1)
- The temporal scale variations of the combined repro2 solutions seem geophysically reasonable (Figure 8, Table 2), making GNSS a potential contributor to the definition of the ITRF2014 temporal scale evolution.
- Inter-AC agreement at ≈2-5 mm for the X and Y geocenter coordinates and ≈5-10 mm for the Z geocenter coordinate (Figure 6, Table 1)
- Non-negligible offsets and rates in the repro2 combined geocenter time series (wrt IGb08; see Table 2)
- Annual geocenter motion: under-estimated along X, over-estimated along Y; out-of-phase with SLR along Z

Earth orientation parameters D

Summary:

- Inter-AC agreement at ≈30-40 µas for pole coordinates; ≈150-200 µas/d for pole rates; 15-30 µs/d for LOD
- Pronounced predominance of **MIT** over combined pole rates and combined LOD. For LOD, this predominance is known to be related to the inter-day constraints applied by **MIT** to empirical orbit parameters. The predominance of **MIT** over the combined pole rates is presumably due to the same reason (to be confirmed).

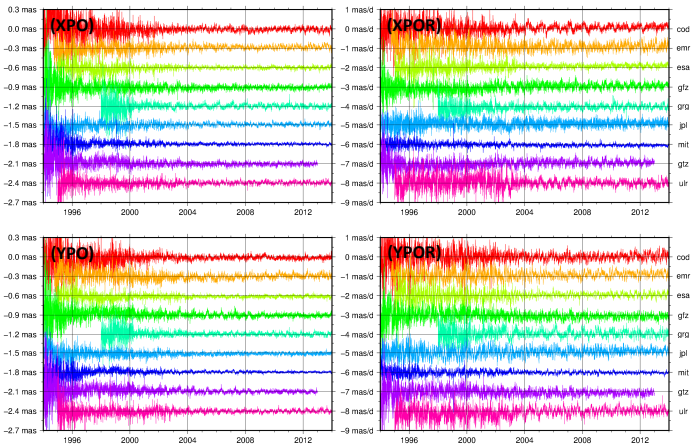

Figure 9: AC pole coordinates and pole rate residual time series

	XPO (µas)	YPO (µas)	XPOR (µas/d)	YPOR (µas/d)	LOD (µs/d)
cod	35	33	170	187	17
emr	39	42	219	186	35
esa	26	26	131	147	16
gfz	36	38	171	180	21
grg	36	30	160	204	16
jpl	29	27	166	174	27
mit	18	17	79	74	17
gtz	28	27	143	148	20
ulr	28	28	181	190	47

Table 3: WRMS of the pole coordinate and pole rate residual time series shown in Figure 9 and of the LOD difference time series shown in Figure 10

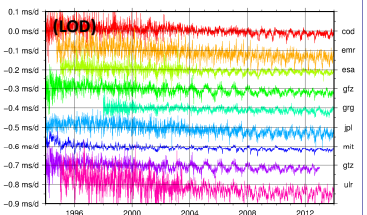

Figure 10: AC minus combined LOD differences. Unlike for polar motion parameters, raw differences are shown instead of the combination residuals. This is because the AC LOD estimates are "calibrated" wrt Bulletin A before combination.

Products / Next steps E

Products:

The repro2 SINEX combination products cover the period from GPS week 730 (January 2, 1994) to GPS week 1831 (February 14, 2015). They consist of the following files for each GPS week wwww:

- ig2yyPwwww[0-6]_all.[snx,ssc]: daily combined SINEX solutions
- ig2yyPwwww[0-6].[snx,ssc]: daily combined SINEX solutions (stations w/o DOMES removed)
- ig2yyPwwww[0-6].res: daily AC – combined residuals
- ig2yyPwwww[0-6]_ITR.res: daily AC – IGb08 residuals
- ig2yyPwwww[0-6]_all.[snx,ssc]: weekly combined SINEX sol.
- ig2yyPwwww.[snx,ssc]: weekly combined SINEX sol. (stations w/o DOMES removed)
- ig2yyPwwww.erp: combined EOPs
- ig2yyPwwww.sum: combination summary

Product availability:

The repro2 SINEX combination products are available at the following FTP servers:

- ftp://igs-rf.ensg.eu/pub/repro2/wwww
- ftp://igs.ensg.eu/pub/igs/products/wwww/repro2
- ftp://igs.ign.fr/pub/igs/products/wwww/repro2
- ftp://cddis.gsfc.nasa.gov/pub/gps/products/wwww/repro2

Next steps:

- Analysis of the combined station position time series:
  - Jump identification → New IGS discontinuity list
  - Modeling of post-seismic deformations
- Preparation of a new IGS cumulative solution based on the daily repro2 combined solutions